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Summary

The influence of fiber elongation on performance of fabric over selected intervals of wear-laundering was measured by certain fabric tests. A significant or highly significant relationship was shown between low elongation cotton and certain fabric properties, whereas, high elongation cotton influenced other fabric properties.

Fabric tear strength and breaking strength were higher by a highly significant difference for low elongation cottons for wear laundered treatments. Fabric tear strength and breaking strength were higher for low elongation cottons both before and after resin treatment. There was no significant difference between cottons for percent add-on of resin. Low elongation cottons were more highly crystalline than high elongation cottons.

Fabric elongation was higher for high elongation cottons. Crease recovery was greater by a highly significant difference. All cottons showed a loss in fabric elongation, breaking strength, and tear strength after resin treatment. However, the percentage losses of resin treated fabrics tended to be greater in the high elongation cottons. This was true of fabric elongation, breaking strength, warp and filling, and filling tearing strength. High elongation cottons showed a higher toughness index for fiber and fabric.

Positive correlations at a significant level were found between fiber elongation and fabric filling elongation and crease recovery.

Acknowledgements

The assistance of Lorraine H. Phillips[1] and Martha C. Jenkins[2] is gratefully acknowledged for their contributions, respectively, to testing of fiber and for investigating the relationship of treated fabric and fiber properties.

Appreciation is expressed to personnel of the Harry D. Wilson Feed and Fertilizer Laboratories, Louisiana State University, and to the Southern Regional Laboratory, United States Department of Agriculture, Agricultural Research Service, New Orleans, Louisiana, for assistance in certain analyses and treatments of fiber and fabric.

Personal thanks are extended to Mr. Joseph M. Leahy, Volkart Brothers, Inc., Dallas, Texas, for assistance in furnishing cotton samples.

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Influence of Cotton Fiber Elongation On Fabric Properties of Type 140 Cotton Sheeting

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Introduction

Sheeting fabric ranks third among the five largest end uses of cotton (*7*). Cotton fiber has been considered the universal standard for sheeting because of its durability, washability and economy. Carded muslin in a plain weave is the principal fabric by volume production. Cotton fiber of suitable quality is required to manufacture yarn and fabric to meet accepted specifications for a particular textile. The properties of raw cotton for a sheeting mix have been characterized as: principal grades, Middling and Strict Low Middling; staple length (32nds inch), 32.5; fibrograph upper half mean (inches), 1.02; fiber uniformity ratios, 78; fiber fineness (micrograms per square inch), 4.4; fiber maturity (percent), 80; moisture content (percent), 6.4; grade index, 96.7; color value, 8.74 (*6*).

Research by private, state and federal agencies supports the hypothesis that properties of length, strength, and fineness of cotton fibers affect processing and are related to fabric properties. However, little information is available on the property of elongation with respect to fabric performance over an extended period of use.

Staten and Saville (*13*) found a difference in the serviceability of sheeting made from three varieties of cotton having similar grade and staple length. Rebenfeld (*10*) studied six experimental cottons having widely different combinations of properties. These cottons were made into sheeting and oxford cloth. Properties of the fibers from the bales and yarns, and properties of fabrics from the scoured, bleached, mercerized, and resin treated states were measured. These data showed that fabric breaking strength and elongation were related to fiber length, strength and elongation.

Grimes and Werman (*3*) found that cotton broadcloth made from selected cottons differing in strength and which were later constructed into men's shirts showed a difference in fabric strength after wear. Fabrics made from the stronger cottons were stronger after wear even though they lost a higher percentage of strength than fabrics made from the weaker fibered cottons.

Rebenfeld (*11*) has stated that raw cotton of low elongation transmitted the property of fiber strength to fabric more efficiently than cottons having higher elongation.

Fiori, *et.al.*, (*2*) reported that cotton having high fiber strength produced yarns having higher strength for any given yarn number or twist than did cotton with low fiber strength.

Sands, *et.al.,* (*12*) made a study to determine transmission of fiber properties to fabric properties. An 80 x 80 fabric construction was made from a high strength cotton (Pressley index 9.20), a medium strength cotton (Pressley index 7.60), and a low strength cotton (Pressley index 6.20). Samples of fabric were tested for fabric strength and elongation and fabric tear strength at the gray, bleached and dyed states. Fabrics made from the stronger-fibered cotton was stronger by a significant difference (0.05 level) over fabric from the cotton lower in fiber strength.

According to Nickerson (*8*) a cellulosic structure such as the cotton fiber has amorphous, accessible, or disordered regions which are more reactive than the crystalline or ordered regions. Reactivity of the amorphous regions affect hygroscopic character, density and ease of swelling, as well as high rate of hydrolysis, oxidation, esterification and etherification. The presence of crystalline regions were associated with rigidity, flexibility, plasticity and extensibility.

Tripp, *et.al.,* (*15*) reported that highly regular hydrogen bonding in the crystalline regions is presumably sufficient to prevent slippage of molecular chains.

Purpose of Study

Selecting fiber by laboratory testing was the first phase of work undertaken in this study of low and high elongation cotton.[1] Purpose of the study was to determine whether the physical property of fiber elongation contributed any inherent effect on physical properties of fabric. Muslin sheeting, type 140, was chosen as the fabric to be used since it represented a market outlet in which a substantial volume of raw cotton is consumed annually. Flat sheets were relatively unaffected by style changes and provided larger areas of fabric for laboratory testing.

Methods and Materials

Part I.—Selection of Fiber

Instruments and procedures prescribed by the ASTM D-13 were used for measurement of the physical properties of length, strength, fineness, elongation and maturity of the cotton fiber and in evaluating fabric after wear and laundering. The problem of selecting cottons in bale lots required screening a total of 202 Classer's samples followed by testing fiber samples from the remaining bales to select four cottons

[1]Work contributed by Louisiana State University to a textile research project, SM-18, for several states in the southern region, "The Evaluation of the Use of Fiber Tests in the Marketing of Cotton and The Relation of Fiber Properties to End-Use Performance."

having the specified range of fiber properties. The determination of fiber properties was done in the Textiles Laboratory at Louisiana State University. Samples for laboratory testing were prepared by hand blending pinches taken from each of the two inside positions of the Classer's sample. Extreme care was exercised to avoid inclusion of any cut fibers in the samples prepared for testing.

Extensive testing was done to select four cottons having close similarity in properties of length, fineness and strength with two bales each having as low and as high a range of elongation as possible. Cottons differing in the property of elongation were referred to as "low" and "high" elongation cottons. Percent elongation of the selected "high" elongation cottons was comparable to the elongation of a representative bale of Pima S-1, 1957 growth. Elongation of the Pima S-1 bale of cotton was 10.9 and 11.8 percent, respectively, as measured by the Textiles Laboratory at Louisiana State University and a collaborating laboratory.[2]

It was also specified that the cottons should be of the same type, growth year, and grade and staple. The four cottons were all American Upland type, produced in 1957, Strict Middling, and of 1-1/16 inch staple according to the Classer's quality evaluation made in accordance with official standards of the United States Department of Agriculture. Three bales of cotton designated by a warehouse code, "Magnolia," were selected from Classer's stocks loaned by the commercial firm.[3] One bale was a registered variety, Stardel, produced and contributed to the project by the Louisiana Agricultural Experiment Station. Information pertaining to the origin of the four cottons is shown in Table 1. Each cotton was assigned a code color which was later used to

TABLE 1.—Identification of the Four Cottons

Code No.	Code Color	Bale Number and/or Variety	Bale Weight	Origin of Growth	Growth Year
1	Blue	*Stardel 624235	565	Bossier City, La.	1957
2	Red	**"Magnolia" 567063	537	Garwood, Tex.	1597
3	Orange	**"Magnolia" EBU–52–941817	502	Milan, Tenn.	1957
4	Black	**"Magnolia" EBU–43–948243	601	Milan, Tenn.	1957

*Denotes a registered variety of cotton developed by the Department of Agronomy, Louisiana State University, and produced at the Red River Valley Agricultural Experiment Station, Bossier City, Louisiana.

**"Magnolia" denotes warehouse identification.

[2]University of Tennessee, Home Economics Research Laboratory and Fiber Research Laboratories.

[3]Through personal courtesy of Mr. Joseph M. Leahy, Volkart Brothers, Inc., Dallas, Texas.

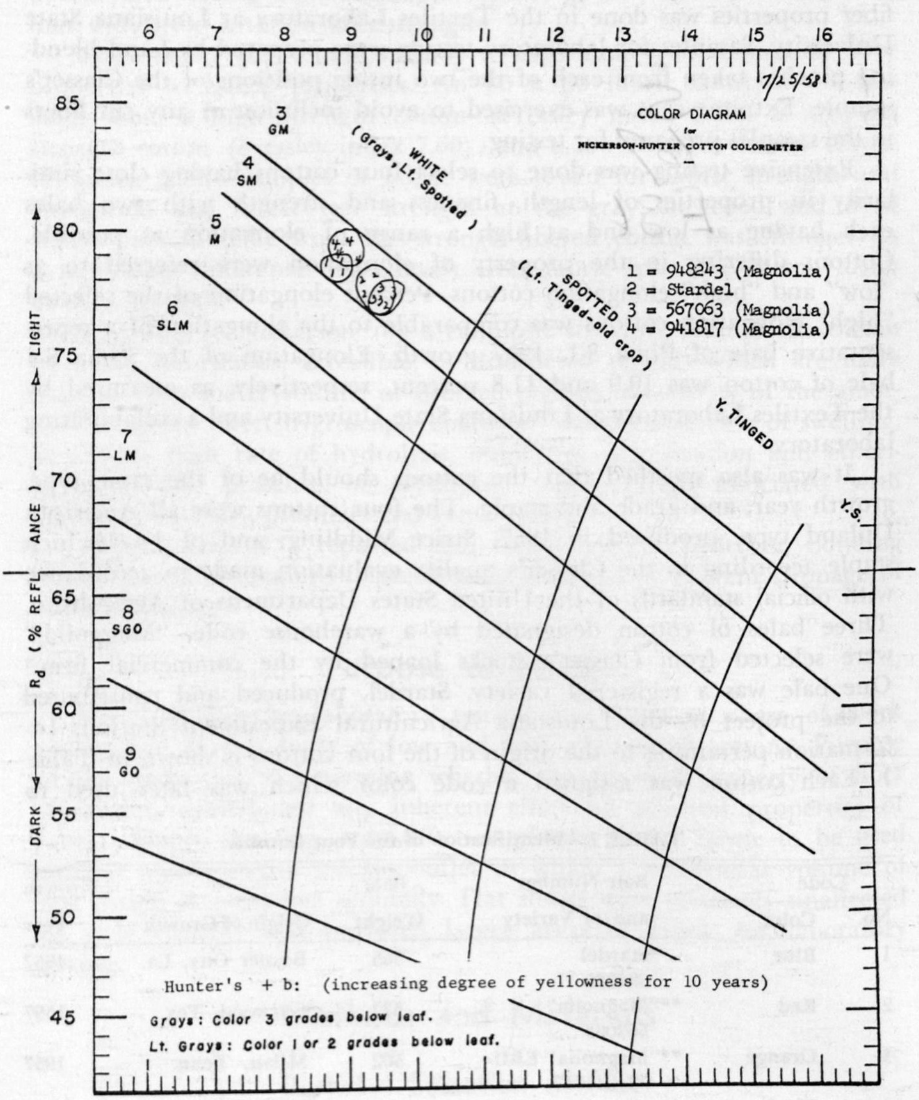


FIGURE 1.—Grade of cotton as measured by Nickerson-Hunter cotton colorimeter.

identify fabric made from each cotton. This was accomplished by weaving a colored yarn in the selvage of the fabric.

Cottons 1 and 2, as identified in Table 1, were paired for close similarity on the basis of "low" fiber elongation and other properties, and cottons 3 and 4 were paired for close similarity in "high" fiber elongation and other properties. The four cottons were as nearly alike in the physical properties of length, fineness and strength as it was

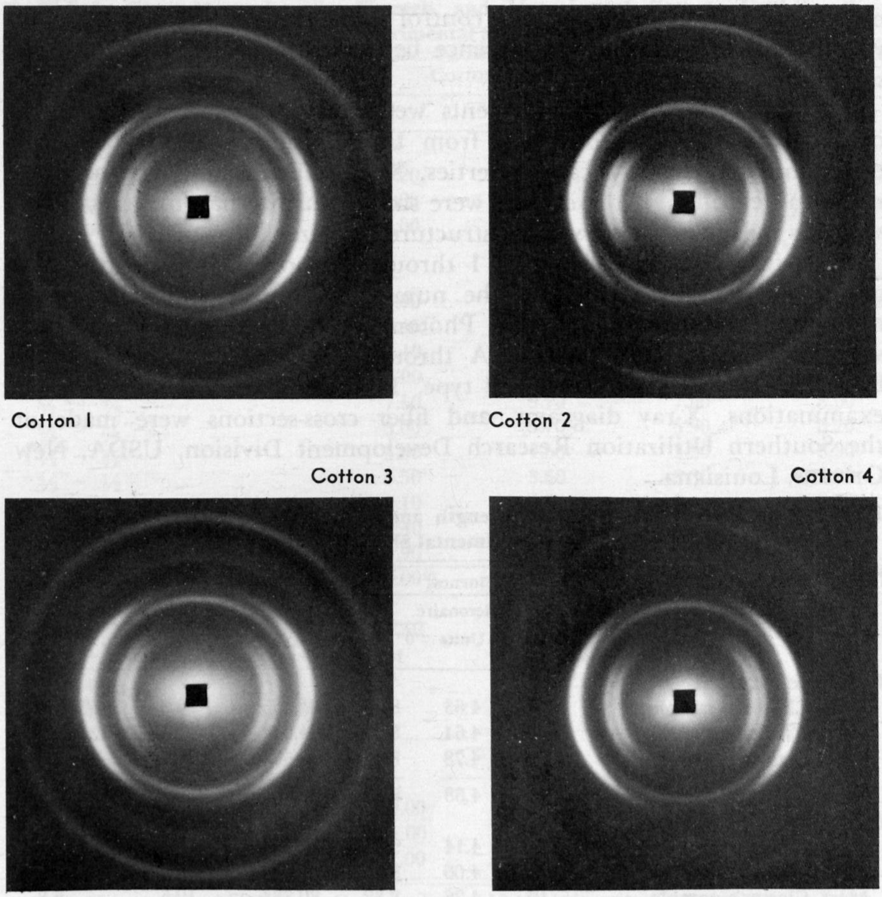


FIGURE 2.—Characteristics of four cottons by X-ray diffraction diagrams (X286).

possible to select and obtain as great a difference as possible in percent elongation. Fiber properties of the selected cottons are shown in Tables 2 and 3.

Color of all four cottons was Strict Middling as measured by the Nickerson-Hunter Cotton Colorimeter. Four readings were made on different layers of each of the four bales, as shown in Figure 1. The narrow range for all readings, as shown by the close clustering of readings in the center of the SM section, indicated well-matched bales.

All four cottons were examined microscopically for biological deterioration. Although the examinations showed presence of fungal hyphae and spores on the fibers in a few areas it was concluded that fungal damage was only slight. A test for the presence of cavitoma was made using a solution of phenolphthalein, sodium hydroxide, distilled water and wetting agent. There was no indication at all of any cavitomic damage in any of the four cottons. As a further check on the presence of cavitoma, the P.B. Marsh alkali swelling test was run on all four samples and a raw control sample. The alkali centrifuge values showed a negligible difference between the control and the test samples.

Although physical measurements were made on fiber of the four cottons and the data obtained from those measurements established close similarity in physical properties, X-ray diffraction diagrams were made to determine if the cottons were similar in internal fiber structure, which is independent of external structure and size.

The four cottons (Figure 2) 1 through 4 showed well defined diagrams and close similarity in the number, diameter and relative intensity of the diffraction rings. Photomicrographs of the fiber cross-sections (Figure 2A), cottons 1A through 4A, showed all cottons to be mature and of similar varietal type. Test for cavitoma, microscopical examinations, X-ray diagrams, and fiber cross-sections were made at the Southern Utilization Research Development Division, USDA, New Orleans, Louisiana.

TABLE 2.—Fiber Length, Fineness, Strength and Elongation of Cottons Used in the Experimental Sheets[1]

Cotton Identification	Length	Fineness	Strength			Elongation
	U.H.M.	Micronaire	Pressley		Stelometer	Percent
	(Inches)	Units	"0" Gauge Length Index	PSI	"1/8" Gauge Length Grams/tex	
1. Stardel–624235						
*1st Classer's sample	1.04	4.63	8.73	94,265	20.8	6.3
*2nd Classer's sample	1.06	4.64	8.79	94,914	19.1	6.6
**1st Classer's sample	1.06	4.78	8.48	91,562	20.4	6.8
Mean	1.05	4.68	8.67	93,580	20.1	6.6
2. Magnolia–567063[2]						
*1st Classer's sample	1.00	4.14	9.09	98,157	19.5	6.1
*2nd Classer's sample	1.00	4.06	8.51	91,887	18.8	6.2
**1st Classer's sample	.97	4.26	8.32	89,833	19.5	6.8
Mean	.99	4.15	8.64	93,292	19.3	6.4
4. Magnolia—EBU—43—948243[2]						
*1st Classer's sample	1.04	4.00	7.48	80,751	18.1	10.0
*2nd Classer's sample	1.04	3.99	7.31	78,913	17.8	10.3
**1st Classer's sample	1.03	4.10	7.13	76,967	19.2	10.0
Mean	1.04	4.03	7.31	78,877	18.4	10.1
4. Magnolia—EBU—43—948243[2]						
*1st Classer's sample	1.02	4.38	7.49	80,859	19.6	10.1
*2nd Classer's sample	1.04	4.27	7.24	78,156	17.4	10.1
**1st Classer's sample	1.03	4.50	7.24	78,156	18.7	9.6
Mean	1.03	4.38	7.32	79,057	18.6	9.9

*Data from Dept. of Home Economics Research (Textiles), Louisiana State University, Baton Rouge, Louisiana.

**Data from Southern Utilization Research and Development Division, USDA, New Orleans.

[1]Supporting fiber work by: Textile Research Department, College of Home Economics, Fiber Research Laboratory and USDA Fiber and Spinning Laboratory, at the University of Tennessee, Knoxville.

[2]Magnolia was a warehouse designation.

TABLE 3.—Fiber Mean Length, Fineness and Maturity of Cottons Used in the Experimental Sheets

Fiber Property	Cotton Identification by Code Number 1.	2.	3.	4.
*Fiber length Array				
Upper quartile (in.)	1.20	1.15	1.22	1.21
Mean (in.)	.98	.95	1.00	1.01
Coef. of variation (pct.)	31.00	29.00	30.00	29.00
Fiber distribution (pct.)				
1½" - 1⅝"	—	—	.50	.50
1⅜" - 1½"	4.00	1.30	4.70	3.90
1⅛" - 1¼"	28.40	21.30	18.90	23.40
1" - 1⅛"	17.10	24.10	23.40	21.70
⅞" - 1"	12.90	17.50	11.70	11.00
¾" - ⅞"	7.50	9.70	7.90	8.00
⅝" - ¾"	5.00	5.70	5.90	6.20
½" - ⅝"	5.00	4.50	3.30	3.90
⅜" - ½"	3.50	3.60	3.30	2.90
¼" - ⅜"	3.10	3.00	3.40	2.50
⅛" - ¼"	2.40	1.60	1.40	1.40
Less than ⅛"	.90	.90	1.00	.60
Total	100.00%	100.00%	100.00%	100.00%
*Fineness by Array				
Fineness-micrograms/in.	4.40	4.20	4.00	4.20
**Fiber Fineness by Arealometer				
A (Mean) MM-1	439.	483.	496.	448.
D (Mean) MM-1	22.	35.	44.	28.
Maturity (percent)				
***Array	89.00	82.00	82.00	84.00
***Causticaire	81.00	77.00	77.00	79.00
*Polarized Light	87.00	82.00	78.00	80.00

*Data reported by Mary Anna Grimes, Texas A&M University, College Station, Texas.
**Data from the Fiber Research Laboratory, The University of Tennessee, Knoxville, Tennessee.
***Data from the US Cotton Laboratory of the Cotton Division, AMS, USDA, College Station, Texas.

Part 2.—Method of Resin Treatment

Under the regional organization, each participating state experiment station was permitted to develop specific research projects. A station project at Louisiana State University, designated 1054, was undertaken to evaluate the relationship between fiber strength and elongation and laboratory performance of resin treated and non-resin treated fabric made from the four cottons used in the regional project. Fiber crystallinity was included because it is believed to be a measure of potential chemical reactivity and thus might be a factor relative to resin uptake. The application of a resin to produce "wash-wear" characteristics is known to modify the fiber and produce significant effects in fabric properties. Fabric properties of tear resistance, fabric tensile strength

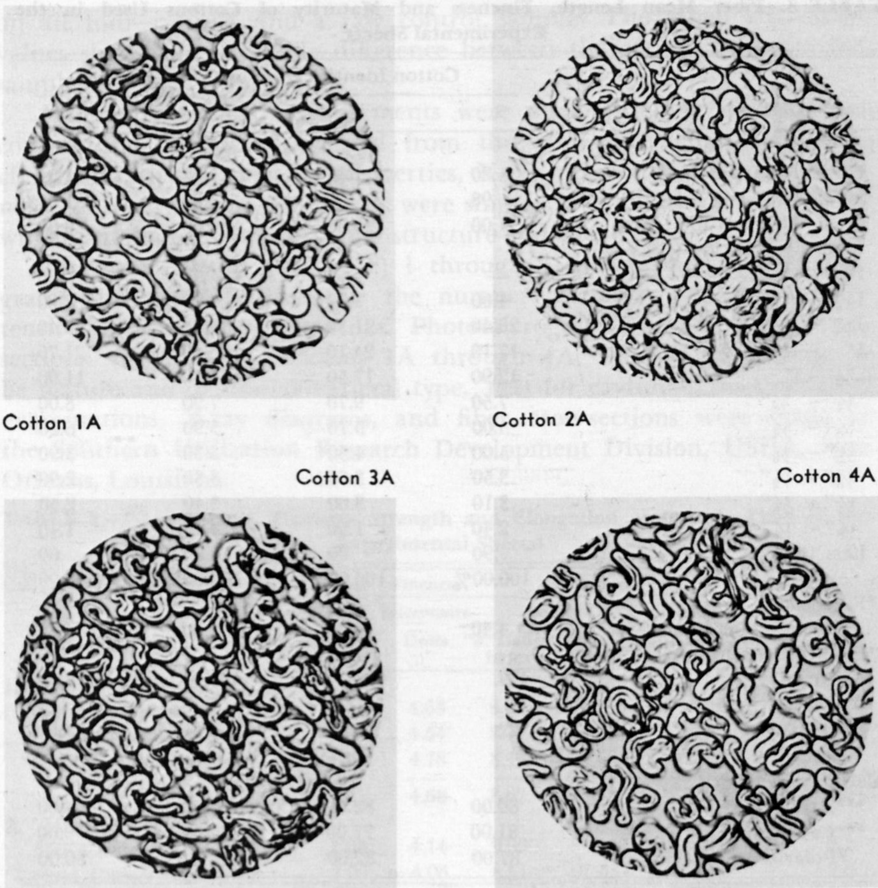
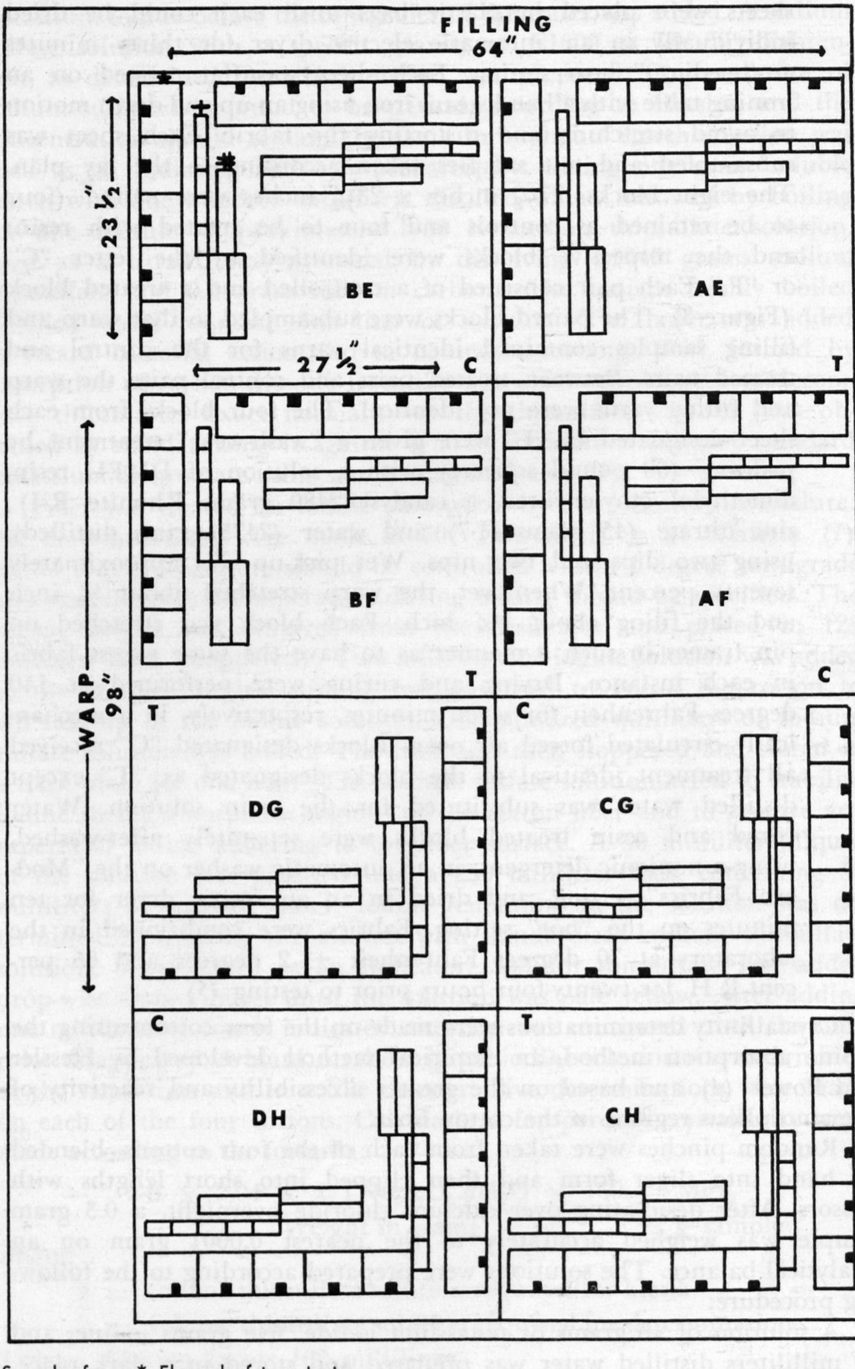


FIGURE 2A.—Characteristics of four cottons in fiber cross section (X286)

and elongation, and crease recovery were measured on the fabric before and after resin treatment.

Fabrics used in the project were four sheets representing each of the four cottons used in the regional project. The four sheets were treated in laboratories of the Chemical Finishing Division of the Southern Utilization Research and Development Division, USDA, New Orleans, Louisiana. Jenkins reported:

> The sheets were desized using an enzyme, since the presence of organic impurities, even in trace amounts, would reduce the effective penetration of the resin into the fabric. The sheets were soaked overnight in a solution of 262.5 grams Rhozme DX, 105 grams Triton X-100, and 15 gallons of water. After soaking they were washed in pairs (low elongation; high elongation) in a solution containing ½ liquid ounce of a liquid detergent to 14 gallons of water in an automatic, agitator type washer, having a twenty-four minute cycle. After washing, the



Samples for: * Elmendorf tear test
Scott tensile strength elongation test
† Monsanto crease recovery test

FIGURE 3.—Plan for sampling, pairing, and subsampling sheets made of two high elongation and two low elongation cottons.

sheets were placed in plastic bags until each could be dried individually in an automatic electric dryer for thirty minutes at "medium" heat setting. Each sheet was flat pressed on an ironing table with a hand steam iron using an up-and-down motion to avoid stretching and distorting the fabric. Each sheet was subsampled and test samples taken according to the lay plan. The eight blocks, 27½ inches x 23½ inches were paired (four to be retained as controls and four to be treated with resin) and the respective blocks were identified by the letter "C" or "F." Each pair consisted of a controlled and a treated block (Figure 3). The paired blocks were subsampled so that warp and filling samples contained identical yarns for the control and treated pairs. Between treated pairs and control pairs the warp and filling yarns were not identical. The four blocks from each sheet designated as "T" were given a "wash-wear" treatment by padding (60 pound squeeze) with a solution of DMEU resin, dimethylol ethyleneurea, a catalyst (480 grams Rhonite R-1), zinc nitrate (45 grams H-7) and water (2475 grams distilled), using two dips and two nips. Wet pick-up was approximately seventy percent. When wet, the warp stretched about ⅝ inch and the filing about 1¼ inch. Each block was stretched on pin frames in such a manner as to have the same excess fabric in each instance. Drying and curing were performed at 140 degrees Fahrenheit for seven minutes, respectively, in a mechanically circulated forced air oven. Blocks designated "C" received all treatment identical to the blocks designated as "T" except distilled water was substituted for the resin solution. Water cured and resin treated blocks were separately after-washed, using a nonionic detergent, in an automatic washer on the "Modern Fabrics" setting, and dried in an automatic dryer for ten minutes on the "hot" setting. Fabrics were conditioned in the laboratory at 70 degrees Fahrenheit $\pm$ 2 degrees and 65 percent R.H. for twenty-four hours prior to testing (*5*).

Crystallinity determinations were made on the four cottons using the iodine absorption method, an empirical method developed by Hessler and Power (*4*) and based on the greater accessibility and reactivity of the amorphous regions in the cotton fiber.

Random pinches were taken from each of the four cottons, blended by hand into sliver form and then clipped into short lengths with scissors. After desiccating over calcium chloride overnight, a 0.3 gram sample was weighed accurately to the nearest 0.0001 gram on an analytical balance. The solutions were prepared according to the following procedure:

A solution of 40 grams of potassium iodide, five grams iodine, and 50 milliliters distilled water was prepared and stored in a dark place. The potassium iodide solution was dissolved in just sufficient water to get it into solution and the iodine was completely dissolved in the potassium iodide before the remainder of the water was added. A sodium sulfate solution with a specific gravity of 1.1600 at 70°-60° Fahrenheit, as determined by a hydrometer, was prepared. Concentration of sodium sulfate was found to be critical, according to Hessler, and the concentration should remain the same throughout. Starch solution was used as an indicator and was prepared by mixing one gram soluble starch with one hundred milliliters distilled water, followed by boiling for one minute. Approximately 1/50 N sodium thiosulfate solution, used as a titrant, was prepared by dissolving 4.9640 grams sodium thiosulfate and 0.2 gram sodium carbonate in enough freshly boiled distilled water to make one liter of solution. The latter was added to retard bacterial action and to neutralize carbonic acid, formed by absorption of carbon dioxide from the air, which would tend to decompose thiosulfate. Exact normality of the thiosulfate solution was obtained by standardizing it against 1/50 N solution of primary standard potassium dichromate using starch as an indicator (*5*).

Fiber was treated for iodine absorption by the following procedure: All determinations were made at 70° Fahrenheit ± 2°. Chitale (*1*) found that temperature should be controlled within 1 degree centigrade and that the actual temperature during testing should be specified. The cotton sample was removed from the desiccator and placed in 125 milliliter flask (stoppered). Two milliliters of iodine solution was added to the sample. A glass stirring rod was used to knead the cotton to aid take-up of the iodine solution. One hundred milliliters of sodium sulfate solution was added. The flask was then stoppered and stored in a dark place for one hour. The sodium sulfate solution acted to stabilize iodine in the amorphous regions of the cotton fiber and to remove any superficial iodine adhering to the fiber surface. A 50 milliliter aliquot of the solution was pipetted into a 250 milliliter flask containing 50 milliliters of distilled water. Iodine remaining in the solution was determined by titrating the aliquot with standardized sodium thiosulfate solution, using starch as an indicator. Sodium thiosulfate was added drop-wise from a buret until the solution was pale yellow. After adding one milliliter of starch indicator, titration was continued until the blue color disappeared. A blank on the original iodine solution was determined at the same time and in a like manner. Five determinations were made on each of the four cottons. Calculations for percent crystallinity were made according to the formula:

$$\frac{a\text{-}b \times 2.04 \times I_2TNa_2S_2O_3.5H_2O \times 100}{\text{Weight in grams}} = \frac{MgI_2}{\text{g sample}}$$

where:

a = volume thiosulfate solution required for blank

b = volume thiosulfate solution required for determination

2.04 = dilution factor $\frac{102 \text{ milliliters}}{50 \text{ milliliters}}$

1000 = factor for converting value to milligrams

$I_2TNa_2S_2O_3.5H_2O$ = iodine titer of thiosulfate solution as calculated from normality

$$\text{Percent amorphous fraction} = \frac{\text{MgI}_2 \text{ per gram sample} \cdot 100}{412}$$

412 = milligrams I_2 absorbed per gram methocel, which was taken as a standard because it gave the highest absorption value according to Hessler.

Percent crystallinity was obtained by subtracting percent amorphous fraction from 100.

The resin uptake of fabrics was measured on the basis of nitrogen content by the Kjeldahl method in the Harry D. Wilson Feed and Fertilizer Laboratories, Louisiana State University.

Results and Discussions

Part I.—Relation of Fiber Properties to Fabric Performance

Each experiment station participating in the regional project was assigned responsibility for measuring certain fabric properties. Two experiment stations collaborated on each of the fabric tests. The data for fabric properties herein reported represents cooperative work by Louisiana. Data for each fabric property were treated in a factorial arrangement by an analysis of variance (Table 5). Differences between low-high cottons were calculated from a statistical analysis of mean values summarizing all intervals.

Louisiana was assigned fabric tear strength on fabric from Alabama and Oklahoma; breaking strength and elongation on fabric from Alabama and Oklahoma; fabric stiffness on fabric from Alabama and Missouri; and rotary abrasion on fabric from Alabama, Missouri, North Carolina, and Oklahoma.

Six sheets were withdrawn at each of the wear-laundering service intervals. These intervals were 0 and after 5, 15, 30, 45 and 60 weeks of use and laundering. In each warp and filling direction of each sheet, seven specimens were tested for stiffness and tear strength, eight specimens were tested for breaking strength and elongation, and six blocks of fabric, 6 x 6 inches, were abraded on the Taber rotary machine. Tear strength was measured on the Elmendorf and breaking strength was measured on a Scott DH model machine.

After each interval of service fabric samples were prepared and abraded by Louisiana and breaking strength tests were made by Oklahoma. Each 6-x-6 inch specimen provided two abraded and two control strips in the dimension to be tested. The strips were cut ¾ inch and ravelled to ½ inch. Fabric strength was reported as the difference between control and abraded specimens.

The mean response for all fabric analyses at each wear-laundering interval showed progressive loss for the property measured.

The index of toughness both for fiber and fabric was measured using the formula[4]:

$$W_1 = \frac{PE}{2}$$

P = stress required to produce rupture
E = strain at the breaking stress

$$\text{Toughness Index} = \frac{\text{breaking strength} \times \text{elongation} \times 100}{2}$$

Toughness index expresses the work, per unit volume of material, which would cause rupture if the stress-strain curve were a straight line. References in the textile literature apply the stress-strain curve as a straight line for fibers, yarns and fabrics.

TABLE 4.—Means for Toughness Index of Fabrics by Wear-Laundering Intervals

	Laundering Intervals (Weeks)					
	0	5	15	30	45	60
Warp						
Low Elongation	4.73	4.14	3.82	2.54	1.67	1.15
High Elongation	5.12	4.49	3.97	2.68	1.76	1.17
Filling						
Low Elongation	6.46	5.36	4.84	3.17	1.85	1.19
High Elongation	6.91	5.62	5.01	3.27	2.07	1.31

Toughness index was calculated by combining data for the two low elongation cottons and the two high elongation cottons as low as and as high for all stations by individual intervals. (Table 4). High elongation cotton was higher in toughness by a significant difference at the 0 and 5 wear-laundering intervals for fabric in the warp direction. Toughness index of high elongation cotton was higher by a significant difference at all intervals in the filling direction.

The mean summary for tear strength of low elongation cotton was higher by a highly significant difference for warp and filling fabric serviced at each station (Table 5). Warp tear strength was higher than filling. Tear strength increased after five weeks of wear and laundering. After fifteen weeks of wear and laundering the level of tear strength was very close to the level of tear strength of the control fabric. This occurred for both stations and in both warp and filling fabric. The increase in tear strength at the fifth-week interval was thought to be due to shift of yarns in the fabric structure which compensated for greater deformation under tearing load. The level of tear strength was substantially reduced between the thirtieth and forty-fifth weeks, and at the terminal interval, the sixtieth week, fabrics showed very slight differences between low-high cottons.

Fabric breaking strength and fabric elongation was determined by the ravelled strip method on the Scott DH-Model Machine (Table 5). The mean summary for these two properties showed low elongation

[4]H. DeWitt Smith. *Textile Fibers—An Engineering Approach to Their Properties and Utilization*. Proceedings of the American Society for Testing Materials. Monograph. (1944) p. 23.

TABLE 5.–Summary of Means for Fabric Tests, Over-All Wear-Laundering Intervals by Station

Test	State	Fabric Direction	Over-All Test Means Cottons 1	2	3	4
Tear Strength (Gram-Centimeters per Centimeter)	Alabama	W	1078**	1053**	1029	1003
		F	964**	952**	883	879
	Oklahoma	W	978**	936**	877	897
		F	857**	820**	747	779
Breaking Strength (Pounds)	Alabama	W	45.1**	44.7**	43.1	44.1
		F	53.9**	51.9**	50.8	51.5
	Oklahoma	W	40.5**	39.9**	38.4	39.3
		F	45.8**	44.9**	42.5	44.6
Elongation (Percent)	Alabama	W	15.0	15.2	17.0**	16.2**
		F	16.3	16.2	18.4**	18.0**
	Oklahoma	W	15.0	14.6	16.0**	15.8**
		F	16.4	15.7	17.3**	17.3**
Stiffness (Centimeter)	Alabama	W	1.76	1.76	1.78	1.79
		F	1.72	1.72	1.73	1.73
	Missouri	W	1.77	1.74	1.74	1.75
		F	1.75	1.73	1.75	1.73
Abrasion (Percent)	Alabama	W	–5.07*	–6.55*	–4.05	–3.99
		F	–5.25	–2.40	–3.41	–4.14
	Missouri	W	–6.62	–5.20	–6.99	–8.39
		F	–4.40	–5.65	–4.48	–6.86
	North Carolina	W	–13.25	–11.09	–12.61	–11.69
		F	8.20	–7.20	–8.22	–6.11
	Oklahoma	W	5.12	–5.63	–7.57	7.34
		F	–8.60	–9.65	–7.96	–6.54

*Significant at 5% level.
**Significant at 1% level.

cottons to be highly significant for breaking strength and high elongation cottons to be highly significant for fabric elongation. The breaking strength for filling fabric was higher than warp strength for all cottons at each separate interval by each station. Filling fabric exhibited higher loss in breaking strength as intervals of wear-laundering progressed. The greatest reduction in pounds breaking strength occurred at the thirtieth-week interval. The differences were smaller between 5 and 15 and 45 and 60 than between 15 and 30 and 30 and 45. Filling fabric elongation was higher than warp elongation.

Fabric stiffness was measured in bending length, and expressed in centimeters (Table 5). All cottons were stiffer at the initial or 0 interval. High elongation cottons were slightly higher in stiffness index than low elongation cottons. Generally the loss in stiffness was greater between 0 and 30 weeks than between 30 and 60. The over-all analysis showed no significant difference between low-high cottons. These findings show that fabric stiffness was not influenced by mechanical properties of the fiber after wear-laundering treatment.

The property of abrasion resistance, measured by rotary head method, was expressed in percent loss in breaking strength of a ½-inch ravelled strip, abraded and unabraded. Loss in strength was indicated by a minus percent for abraded samples (Table 5). Low and high elongation cottons were not statistically different.

Part 2.—Resin Treatment

The four cottons were ranked 1, 2, 3, 4 by the "f" test for crystallinity determinations. Cottons 1 and 2, 91.43 percent and 90.09 percent, and cottons 3 and 4, 89.20 percent and 84.23 percent, were significantly different (Table 6). These data are in agreement with work of Nickerson (*8*) and Ward (*16*) who reported that high crystallinity was associated with low elongation and high strength.

There was no significant difference among cottons for resin add-on when analyzed by the "f" test (Table 7). Differences in crease recovery among cottons was eliminated due to this factor.

A highly significant difference was found between treated and untreated fabric as evidenced by loss in fabric breaking and tear strength, fabric elongation, and a gain in fabric recovery from creasing (Table 8). These data show changes in the functionally important properties of fabric which are in agreement with researches reported by Reid, *et.al.* (*14*), Orr, *et.al.* (*9*), Tripp *et.al.* (*15*), and Rebenfeld (*10*).

Breaking and tear strength were higher for the low elongation cottons both before and after resin treatment.

A highly significant difference was found for crease recovery between treated fabric for all cottons in both warps and filling. High elongation cottons were significantly higher in the filling for treated fabric.

Differences in fabric properties by percent loss are shown in Table

TABLE 6.—Means for Fiber Crystallinity and Fiber Toughness Index for Four Cottons

	Cottons 1	2	3	4
Crystallinity Percent	91.43	90.09	89.20	84.23
Toughness Index	6.63	6.18	9.29	9.21

TABLE 7.—Means for Percent Add-on of Resin for Four Cottons

	Cottons 1	2	3	4
Warp	5.46	5.06	5.88	5.62
Filling	5.63	5.23	5.36	5.80

9. The high elongation cottons lost a higher percent in fabric elongation than the low elongation cotton.

The breaking strength of fabrics before resin treatment was relative to that after treatment for both warp and filling samples. A significant difference in breaking strength was found for treated fabric in the filling for low elongation cotton.

A highly significant difference in breaking strength was found for low elongation cotton in both the warp and filling direction.

Positive correlations were found between fiber elongation, fabric elongation, and fabric crease recovery in the filling direction (Table 10).

TABLE 8.—Mean Values of Laboratory Tests of Fabric Properties for Water Cured and Resin Treated Fabric in the Warp and Filling Directions.*

	Breaking Strength (pounds)		Elongation (percent)		Tear Strength (hundred grams)		Crease Recovery (degrees)	
Cotton	Control	Treated	Control	Treated	Control	Treated	Control	Treated
Warp								
1	63.22	34.85	13.64	9.92	10.70	5.62	73.00	129.65
2	63.92	36.25	15.97	10.50	10.85	5.30	71.30	133.05
3	60.18	33.21	16.67	10.81	10.42	5.32	81.00	135.60
4	65.52	35.56	17.11	10.22	10.21	5.22	70.85	133.50
Filling								
1	74.18	46.64	19.22	12.53	10.08	4.95	77.35	133.70
2	69.42	41.40	18.55	12.58	9.80	4.77	73.95	133.70
3	68.23	36.78	23.04	13.92	9.00	4.12	83.05	142.30
4	69.00	38.86	20.67	13.44	9.28	4.20	89.55	144.95

*Each value for tensile strength and elongation represents 12 tests and each value for tear strength and crease recovery represents 20 tests.

TABLE 9.—Differences in Fabric Properties Due to Resin Treatment as Expressed by Percent Loss or Percent Gain for Warp and Filling Samples

Cottons	Breaking Strength % Loss	Elongation % Loss	Tear Strength % Loss	Crease Recovery % Gain
Warp				
1	44.88	27.27	47.48	42.69
2	43.29	34.25	51.15	46.27
3	44.82	35.15	48.98	40.27
4	45.73	40.27	48.87	46.83
Filling				
1	45.21	34.81	50.89	42.15
2	40.36	32.18	51.33	44.68
3	46.09	39.58	54.22	41.64
4	44.48	34.98	54.74	38.22
Warp + Filling*				
1	45.05	31.04	49.18	42.92
2	41.82	33.22	51.24	45.55
3	45.46	37.36	51.60	40.96
4	45.10	37.62	51.80	42.58

*Values represent an average of percent losses in warp and filling.

TABLE 10.—Correlation Coefficients for all Relationships Between Fabric Measurements and Certain Fiber Properties

Fabric Property	Fiber Properties		
	Strength	Elongation	Crystallinity
Warp			
Tensile Strength			
Water Cured	0.22	–0.22	–0.51
Resin Treated	0.36	–0.56	–0.17
Elongation			
Water Cured	–0.95**	0.75	–0.76
Resin Treated	–0.75	0.46	–0.04
Tear Strength			
Water Cured	0.71	–0.93**	0.85*
Resin Treated	0.85*	–0.59	0.74
Crease Recovery			
Water Cured	–0.44	0.50	0.25
Resin Treated	–0.95**	0.73	–0.43
Filling			
Tensile Strength			
Water Cured	0.89*	–0.58	0.40
Resin Treated	0.79	–0.92**	0.37
Elongation			
Water Cured	–0.77	0.88*	–0.30
Resin Treated	–0.90*	0.96**	–0.53
Tear Strength			
Water Cured	0.97**	–0.94**	0.59
Resin Treated	0.97**	–0.98**	0.71
Crease Recovery			
Water Cured	–0.68	0.89*	–0.88*
Resin Treated	–0.86*	0.97**	–0.85*

*Significant at 5 percent level.

**Significant at 1 percent level.

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